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(U) The report describes a computer program that predicts the flight trajectory, spin decay, and gyroscopic and dynamic stability factors for spin- or fin-stabilized cannon-launched projectiles with liquid or solid payloads.

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PREFACE

The work described in this report was accomplished as support effort for several projectile research and development programs being conducted at Chemical Systems Laboratory. The work was started in September 1976 and completed in September 1977. The computer program is general in nature and should be applicable to any study of a projectile's trajectory.

Work was authorized under Project 1L162622A554-1, Lethal Chemical Weapons Technology.

SUMMARY

This report describes a computer program that predicts the flight trajectory, spin decay, and gyroscopic and dynamic stability factors for spin- or fin-stabilized cannon-launched projectiles with solid or liquid payloads. The program provides a fast, accurate, and efficient method of evaluating projectile trajectories. A short introduction provides the mechanics of trajectory theory. However, no effort is made to give a complete mathematical analysis of the theory. The theory may be found in the literature cited (given as footnotes in the report).

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A COMPUTER PROGRAM FOR ANALYZING PROJECTILE FLIGHT TRAJECTORY

I. INTRODUCTION.

The purpose of this report is to present a computer program that assists design personnel in analyzing projectile flight. After aerodynamic coefficients for a proposed munition shape are derived from wind tunnel tests, a prediction of projectile stability, range, and accuracy must be made. In addition, the effect on projectile flight of a liquid payload or shift in center-of-gravity location may be required. This program can be used as a design tool in analyzing projectile flight.

II. THEORY.

A. Simple Particle Trajectory.

As in any trajectory, simple particle trajectory is the curve traced by the center of gravity of a projectile with respect to a horizontal surface when fired at a particular charge/elevation combination. However, simple particle trajectory uses velocity and aerodynamic drag to calculate the horizontal and vertical velocity components.

The fundamental equations used in the computer program are:

$$\Delta V = \left(\frac{-\,\text{drag}}{\text{projectile mass}} - g \sin\theta \right) \Delta t \tag{1}$$

$$\Delta\theta = \left(\frac{-g\cos\theta}{V} \right) \Delta t \tag{2}$$

$$\Delta X = (V\cos\theta)\ \Delta t \tag{3}$$

$$\Delta Z = (V\sin\theta)\ \Delta t \tag{4}$$

where

V = projectile velocity

θ = acute angle between a horizontal plane and the tangent to the trajectory at the projectile center of mass

g = gravitational constant

t = time

X = horizontal distance

Z = height above horizontal plane

B. Spin Decay for Liquid-Filled Projectiles.

When a projectile is fired from a gun, the liquid, initially, is not rotating with the projectile. During the down-range flight, the liquid acquires angular momentum from the projectile and the liquid spin rate approaches that of the projectile. This process of the liquid acquiring angular momentum is referred to as the spinup process. This process, whereby the liquid acquires angular momentum from an initial condition of zero rotation, was explained by Wedemeyer.* Wedemeyer showed that for the case of a completely filled cylinder, viscous regions, known as Ekman layers, near the end walls act as centrifugal fans sucking non-rotating liquid from the inviscid core and throwing the liquid outwards.

To incorporate liquid effects (spinup process) on rigid body spin decay, the difference between rigid body rotation and zero liquid rotation at the muzzle is calculated. The theoretical spin decay assumes a percentage of liquid rotating with the projectile at muzzle exit. The particular decay curve (see the figure) for the percentage of liquid rotating with the projectile at muzzle exit is:

$$y = a^t \qquad (5)$$

where

a = percentage of liquid rotating with the projectile at muzzle exit.

t = time after launch

y = spin decay correction factor.

The decay curve asymptotically approaches the t-axis. The value of y (equation 5) is multiplied by the difference between rigid body payload rotation and zero payload rotation at muzzle exit to determine projectile spin decay due to liquid effects.

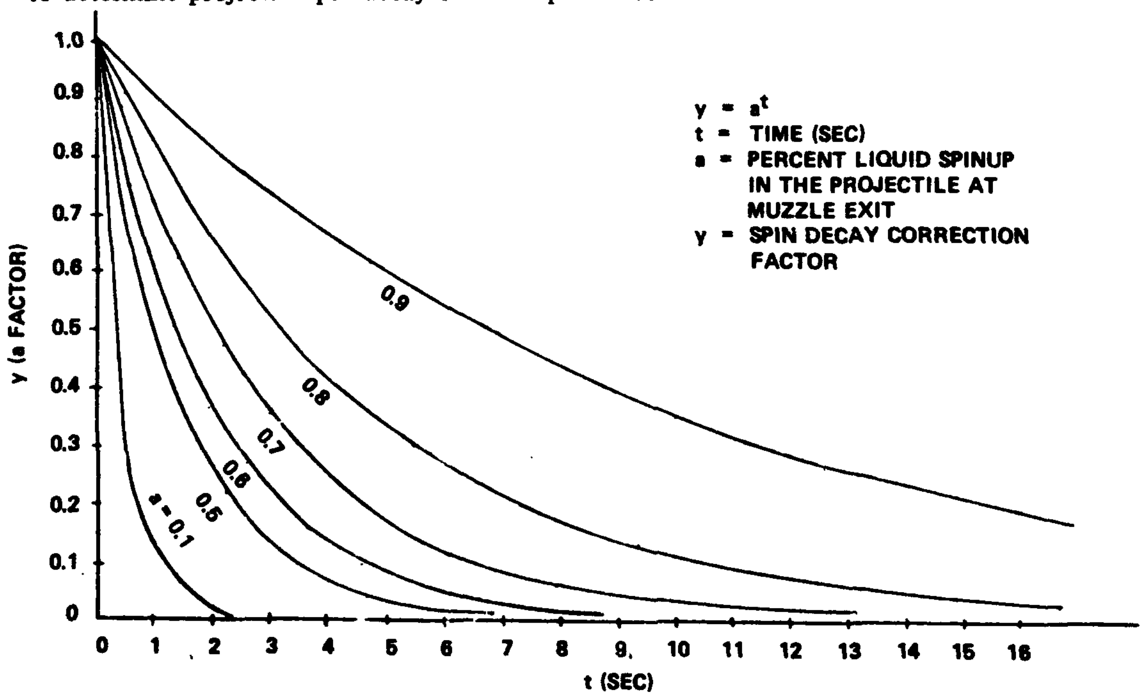

Figure. Spin Decay Curves for Liquid-Filled Spin-Stabilized Projectiles

* Wedemeyer, F. H. BRL Report 1252. The Unsteady Flow Within a Spinning Cylinder. Aberdeen Proving Ground, MD 21005. 1963.

C. Roll Rate For Fin-Stabilized Munitions.*

Unlike spin-stabilized projectiles whose spin is generated by the gun tube rifling, fin-stabilized munitions generate spin by the air flowing over the canted fin blades. The spin equilibrium roll rate, p_e, for fin munitions is:

$$p_e = \frac{-C_{ls} \ VS_{fc}}{C_{lp} \ d} \tag{6}$$

where

C_{ls} = roll moment coefficient due to fin cant (at zero spin)

C_{lp} = roll damping-moment coefficient

S_{fc} = fin cant angle, radians

V = velocity, ft/sec

d = maximum projectile body diameter, ft

Theoretically, resonance instabilities can occur in spin-stabilized projectiles due to the coincidence of spin and yaw frequencies, however, this phenomenon is more likely to occur with fin-stabilized projectiles. The spin is most likely to coincide with nutational frequency $\dot{\phi}_1$, given by:

$$\dot{\phi}_1 = \frac{P}{2} + \left(\frac{P^2}{4} - M\right)^{0.5} = \frac{P}{2} \left(1 + (1\text{-}1/S_g)^{0.5}\right. \tag{7}$$

where

S_g = gyroscopic stability factor

$$M = \frac{\rho S d^3}{2I_y} C_{Ma}$$

C_{Ma} = static moment coefficient, per radian

d = maximum body diameter, ft

ρ = air density, slug/ft^3

S = projectile cross-sectional area, ft^2

---

*Engineering Design Handbook AMCP 706-242. Design for Control of Projectile Flight Characteristics. Headquarters, US Army Materiel Command, Washington, D.C. 1966.

$$P = \frac{I_x}{I_y} \text{ and } \dot{\phi}_1 = \frac{pd}{V}$$

$\bar{u}$ = static moment factor (per radian)

p = spin in radian per caliber of travel

I_x = axial moment of inertia, slugs - ft^2

I_y = transverse moment of inertia, slugs - ft^2

This reduces to a resonance roll rate, p_r, represented as:

$$p_r = \left(\frac{-u}{I_y - I_x}\right)^{0.5}$$

It has been suggested that the roll rate at exit for a fin munition fired from a rifled tube should be three times resonance roll rate. A fin munition fired from a smooth-bore tube exits with zero spin. Theory states that munition roll rate will pass through resonance roll rate prior to equilibrium roll rate. The greater the equilibrium roll rate/resonance roll rate ratio the shorter time the projectile is in the vicinity of resonance roll rate, thus temporary growth in yaw due to resonance will be insignificant.

III. THE PROGRAM.

The program given in Fortran symbols on pages 13 through 20 calculates the flight trajectories of spin- and fin-stabilized projectiles with liquid or solid payloads. The input parameters (i.e., launch conditions, aerodynamic coefficients, projectile physical characteristics) required are listed at the beginning of the program. The program consists of three parts (1) the main program calculates trajectory and stability, (2) a subroutine calculates the liquid effects on projectile spin, and (3) a subroutine calculates equilibrium and resonance roll rates for a fin-stabilized munition. Sample outputs for solid and liquid spin-stabilized projectiles are shown in tables 1 and 2. Table 3 shows an output for fin-stabilized projectiles.

```
C        LINEAR INTERPOLATION INPUT
C ENGINEERING DESIGN HANDBOOK AMCP706-242
C CALC FLIGHT TRAJECTORY OF PROJECTILE
C DATA CARD 1
C IJ = NUMBER OF TIMES PROGRAM EXECUTES
C K= NUMBER OF COEFFICIENT CARDS
C INC= TIME INCREMENT FOR PRINT OUT INC=.02SEC
C JC = 0 - ALL AERO COEFFICIENTS. 1 -  VELOCITY.DRAG ONLY
C JA = 0 - SOLID PAYLOAD. 1 - LIQUID PAYLOAD
C JB =0 - STABILITY FACTOR CALC. 1 - NO STABILITY FACTOR CALC
C JD= 0 - SPIN STAB MUN. 1 - FIN STAB MUN
C DATA CAR. 2 TO N
C CDT = DRAG COEFFICIENT FOR VT
C VT = VELOCITY
C CMA COEFFICIENT
C SAG - MAGNUS COEFFICIENT
C CLA= LIFT COEFFICIENT
C DAM= DAMPING MOMENT COEFFICIENT
C CLS= ROLL MOMENT COEFFICIENT
C CLPO= SPIN DECELERATION COEFFICIENT
C DATA CARD
C THETO = ANGLE OF FIRE . DEG
C V0 = INITIAL VELOCITY. FT/SEC
C Z0 = INITIAL HEIGHT. FT
C WT = WEIGHT OF SHELL. LB
C DEN = AIR DENSITY. LB/CUFT
C S = AREA OF SHELL.SQFT
C RANGE = INITIAL RANGE. FT
C DATA CARD
C AXMO = AXIAL MOMENT OF SHELL. LB-SQFT
C TWIST = TWIST OF SHELL. CAL/TURN
C DIA= DIAMETER OF SHELL. FT
C ZMSL = HEIGHT ABOVE SEA LEVEL. FT
C TRANA = TRANSVERSE MOMENT OF SHELL. LB-SQFT
```

```
      C DATA CARD
      C AXM = AXIAL MOMENT OF SHELL RIGID PARTS, LB-SQFT
      C WRR = WEIGHT OF SHELL RIGID PARTS, LB
      C PL PERCENT SPINUP/100
      C TMAX= TIME USING LIQUID SPIN CURVES
      C DATA CARD
      C SFC= FIN CANT ANGLE,RADIAN
      C P= INITIAL SPIN AT,MUZZLE,REV/SEC
            COMPLEX SPRC1
            DIMENSION VT(50),CDT(50),CMA(50),SAG(50),CLA(50),DAM(50)
            DIMENSION CLS(50),CLPD(50)
            COMMON/BLK1/CSL,SFC,CLDP,OPT,P,T
            COMMON/BLK2/DEN,V,S,DIA,DELT
            COMMON/BLK3/CM,SPIN,PRATIO,AXMS,TRAN
            COMMON/BLK4/B,W,TT,TMAX
      C READ COEFFICIENTS
            READ(5,15) IJ,K,INC,JC,JA,JB,JD
         15 FORMAT(2I2,I4,4I2)
            READ(5,57) (VT(I),CDT(I),CMA(I),SAG(I),CLA(I),DAM(I),
           1CLS(I),CLPD(I),I=1,K)
         57 FORMAT(8F10.4)
            WRITE(6,70)
         70 FORMAT(/,31X,25H AERODYNAMIC COEFFICIENTS)
            WRITE(6,58)
         58 FORMAT(/,1X,9H VELOCITY,1X,10H DRAG COFF,3X,4H CMA,3X,
           112H MAGNUS COEF,1X,10H LIFT COEF,3X,12H DAMPING MOM,
           23X,9H ROLL MOM,3X,10HSPIN DECEL)
            WRITE(6,59) (VT(I),CDT(I),CMA(I),SAG(I),CLA(I),DAM(I),
           1CLS(I),CLPD(I),I=1,K)
         59 FORMAT(4F10.4,3X,F10.4,3X,F10.4,3X,F10.4,3X,F10.4)
      C READ DATA
            DO 435 JK=1,IJ
        100 READ (5,1) THETO,VO,ZO,WT,DEN,S,RANGE
            READ(5,11) AXMO,TWIST,DIA,ZMSL,TRANA
            IF(JA.EQ.0) GO TO 87
            READ(5,62)AXM,WRR,PL,TMAX
         87 IF(JB.EQ.0) GO TO 25
            READ(5,11) SFC,P
            SPIN=P
         62 FORMAT(8F10.3)
          1 FORMAT(8F10.3)
         11 FORMAT(5F10.3)
         25 WRITE(6,13)
         13 FORMAT(///7X,18H INITIAL CONDITIONS)
      C WRITE DATA
          2 WRITE(6,400) THETO,VO,ZO,WT,DEN,S,RANGE,AXMO,TWIST,DIA,ZMSL,
           1TRANA
        400 FORMAT(/1X,22H THETO(DEG)              =,F9.3/1X,
           122H VO(FT/SEC)              =,F9.3/1X,22H ZO(FT)              =,
           2F9.3/1X,22H WT(LB)              =,F9.3/1X,
           322H DEN(LB/CUFT)              =,F9.3/1X,22H S(SQFT)              =,
           4F9.3/1X,22H INITIAL RANGE              =,F9.3/1X,
           522H SHELL AXMO(LB-SQFT) =,F9.3/1X,
           622H TWIST(CAL/TURN)              =,F9.3/1X,22H SHELL DIA(FT)              =,
           7F9.3/1X,22H HEIGHT ABOVE SEA(FT)=,F9.3/1X,
           822H SHELL TRMO(LB-SQFT) =,F9.3)
            IF(JA.EQ.0) GO TO 320
```

```
      WRITE(6,25)AXM,WRR,B,TMAX
   25 FORMAT(1X,22H RIGID AXMO(LB-SQFT) =,F9.3/1X,
     122H RIGID WT(LB)          =,F9.3/1X,
     222H PERCENT SPINUP/100   =,F9.3/1X,
     322H LIQ SPINUP TIME(SEC)=,F9.3/)
  320 IF(JD.EQ.0) GO TO 321
      WRITE(6,28) SFC,P
   28 FORMAT(1X,22H FIN CANT ANG(RADIAN)=,F9.3,/1X,
     122H INITIALSPIN(REV/SEC)=,F9.3///)
  321 THETO=THETO*3.14159/180.
      WRITE(6,7)
    7 FORMAT(60X,15HTRAJECTORY PLOT)
      IF(JA.EQ.0) GO TO 365
      WRITE(6,366)
  366 FORMAT(/45X,42H THEORETICAL LIQUID FILLED PROJECTILE SPIN,/)
  365 WRITE(6,8)
    8 FORMAT(8X,4HTIME,4X,4HTRAJ,5X,5HHORIZ,5X,4HVERT,6X,3HVEL,6X,
     13HACC,5X,3HACC,5X,4HDRAG,6X,2HCD,7X,3HDEN,5X,4HSPIN,8X,3HYAW,/,
     116X,5HANGLE,4X,4HDIST,32X,5HANGLE,39X,4HREAL,4X,3HIMG,/,
     17X,5H(SEC),4X,5H(DEG),4X,3H(M),8X,3H(M),2X,9H(FT/SEC),
     13X,4H(FT/,6X,3HDEG,3X,6H(FTLB-,14X,4H(LB/,
     15X,5H(REV/,7X,5H(DEG),/,51X,7HSEC SQ),10X,7HSEC SQ),
     112X,6HFT CU),5X,3HSEC)
C INITIALIZATION
      X1=RANGE/3.281
      X=RANGE
      TI=0.0
      IF (Z0.GT.0.0) GO TO 29
      Z0=.01
   29 Z=Z0
      Z1=Z/3.281
      T=0.0
      THETA=THETO
      DELT=0.02
      V=V0
      IF(TWIST.EQ.0) GO TO 435
  430 TWISTO=TWIST
      TWISTL=TWIST
      SRPC=6.28318/TWIST
      GO TO 438
  435 SRPC=(6.28318*P*DIA)/V
  438 SRPCO=SRPC
      AXMS=AXMO/32.17
      AXMP=AXM/32.17
      WW=WT/32.17
      WR=WRR/32.17
      TRAN=TRANA/32.17
      OPT=0
      KOPT=0
      VDEN=DEN
      DENSL = (EXP(ZMSL/22000.0))*DEN
C DETERMINE DRAG,CMA,MAGNUS
   16 IF(V.LT.VT(1)) GO TO 34
      GO TO 18
   34 V=VT(1)
   18 J=2
   20 IF (V-VT(J))112,111,110
```

```
  110 J=J+1
  500 IF(J.LT.K) GO TO 69
      WRITE(6,55)
   55 FORMAT(1X,20H ERROR STATEMENT 500)
      STOP
  111 CD=CDT(J)
      CM=CMA(J)
      SA=SAG(J)
      DA=DAM(J)
      CSL=CLS(J)
      CLDP=CLPD(J)
      CL=CLA(J)
      IF (OPT.GT.0) GO TO 40
      GO TO 81
  112 CD=CDT(J-1)+(CDT(J)-CDT(J-1))/(VT(J)-VT(J-1))*(V-VT(J-1))
      CM=CMA(J-1)+(CMA(J)-CMA(J-1))/(VT(J)-VT(J-1))*(V-VT(J-1))
      SA=SAG(J-1)+(SAG(J)-SAG(J-1))/(VT(J)-VT(J-1))*(V-VT(J-1))
      DA=DAM(J-1)+(DAM(J)-DAM(J-1))/(VT(J)-VT(J-1))*(V-VT(J-1))
      CSL=CLS(J-1)+(CLS(J)-CLS(J-1))/(VT(J)-VT(J-1))*(V-VT(J-1))
      CLDP=CLPD(J-1)+(CLPD(J)-CLPD(J-1))/(VT(J)-VT(J-1))*(V-VT(J-1))
      CL=CLA(J-1)+(CLA(J)-CLA(J-1))/(VT(J)-VT(J-1))*(V-VT(J-1))
      IF (OPT.GT.0) GO TO 40
   81 NCNT1=0
      NCNT2=0
C VELOCITY COMPONENTS
      VX=V*COS(THETA)
      VZ=V*SIN(THETA)
      FACTOR = .5*DEN*CD*S
      GO TO 169
   40 FACTOR = .5*VDEN*CD*S
C DRAG COMPONENTS
  169 DRAG=FACTOR*V*V
      DX=DRAG*COS(THETA)
      DZ=DRAG*SIN(THETA)
C ACCELERATION
      AX=-DRAG/WT*COS(THETA)
      AZ=-DRAG/WT*SIN(THETA)-32.17
      THEACC=ATAN2(AZ,AX)
      A=SQRT(AX*AX+AZ*AZ)
      IF(Z) 50,50,45
   45 THEACC=THEACC*180./3.14159
      THETA=THETA*180./3.14159
C PRINT OUT INTERVAL
      IF (NCNT1.NE.NCNT2) GO TO 21
      IF(JD.EQ.1) GO TO 360
  705 FORMAT(4F15.4)
      SPR=VO/(DIA*TWISTO)
      SPIN=SPR
      IF(JA.EQ.0) GO TO 360
      SPINL=VO/(DIA*TWISTL)
      SPIN=SPINL
  360 IF(JC.GT.0) GO TO 300
      WRITE(6,2) T,THETA,X1,Z1,V,A,THEACC,DRAG,CD,VDEN,
     1SPIN,SPRCL
    2 FORMAT(1H,2X,6F9.2,2F9.5,1F9.2,2F7.3)
      GO TO 310
  300 WRITE(6,4) T,THETA,X1,Z1,V,A,THEACC,DRAG,CD,VDEN,SPIN
```

```
    4 FORMAT(3X,8F9.2,2F9.5,1F9.2)
  310 NCNT1=NCNT1+INC
   21 NCNT2=NCNT2+1
      VXSAVE=VX
      VZSAVE=VZ
      VSAVE=SQRT(VXSAVE*VXSAVE+VZSAVE*VZSAVE)
      THETAS=ATAN2(VZSAVE,VXSAVE)
      TSAVE=T
      XSAVE=X
      ZSAVE=Z
      DXSAVE=DX
      DZSAVE=DZ
      AXSAVE=AX
      AZSAVE=AZ
C INCREMENTING TRAJECTORY
      DELVX=AX*DELT
      DELVZ=AZ*DELT
      DELX=DELT*(VX+.5*DELVX)
      DELZ=DELT*(VZ+.5*DELVZ)
      VX=VX+DELVX
      VZ=VZ+DELVZ
      T=T+DELT
      THETA=ATAN2(VZ,VX)
      V=SQRT(VX*VX+VZ*VZ)
      X=X+DELX
      XDIST=X-XSAVE
      X1=X/3.281
      Z=Z+DELZ
      ZDIST=Z-ZSAVE
      VDEN = (EXP((-ZMSL-Z)/22000.0))*DENSL
      IF (VDEN.LE.DEN) GO TO 43
      VDEN = DEN
   43 Z1=Z/3.281
C SPIN CALCULATION
      FAC=VDEN*.785*DIA*DIA/(2.0*WT)
      IF(JD.EQ.0) GO TO 214
      CALL FIN
  214 DIST=SQRT(XDIST*XDIST+ZDIST*ZDIST)
      RGA=WW*DIA**2./AXMO
      RGT=WW*DIA**2./TRAN
      ARATIO=COS(THETA)/(COS(THETAS))
      CLP=-CD/(3.0*RGA)
      COE=RGA*CLP+CD
      SRPC=SRPCO*ARATIO*(EXP(FAC*DIST*COE))
      TWISTO=(6.28318*VO)/(SRPC*V)
      SRPCO=SRPC
      IF(JA.EQ.0) GO TO 370
      IF(TI.GE.TMAX) GO TO 370
      DSRPC=SRPC*(AXM/AXMO)
      SP1=SRPC-DSRPC
      CALL DECAY
      SP2=W*SP1
      SPL=SP2+DSRPC
      TWISTL=(6.28318*VO)/(SPL*V)
      IF(TI.GE.TMAX) GO TO 371
      GO TO 370
  371 IF(KOPT.EQ.2) GO TO 370
```

```
      TWISTO=TWISTL
      SRPCO=SPL
      JA=0
      KOPT=2
C YAW CALCULATION
  370 ADEN=VDEN/32.17
      SPRC=SRPC*(1./DIA)*V
      YAW1=AXMS*SPRC*32.17*COS(THETA)
      YAW2=.5*ADEN*S*DIA*CM*V**3.
      YAW3=(YAW1/YAW2)*180./3.14159
      YAW4=(SA*SPRC*DIA)/(CM*V)
      YAW5=(YAW3*YAW4)*180./3.14159
      SPRC1=CMPLX(YAW3,YAW5)
      IF(OPT.GT.0) GO TO 35
C U= STATIC MOMENT FACTOR, LB-FT/RADIAN
      U=.39269*ADEN*DIA**3.*V**2.*CM
      IF(JB.GT.0) GO TO 35
      IF(JA.GT.0) GO TO 36
C SOLID FILLED PROJECTILE
C GYROSCOPIC STABILITY FACTOR
      SG=(AXMS**2.*SPRC**2.)/(4.*TRAN*U)
C DYNAMIC STABILITY ESTIMATE
      SD1=2.*(CL+RGA*SA)
      SD2=CL-CD+(-RGT*DA)
      GO TO 37
C LIQUID FILLED PROJECTILE
   36 SG1=(AXMS**2.*SPRC**2.)/(4.*TRAN*U)
      SG2=AXMR/AXMS
      SG=SG1*SG2**2.
      RGAR=(WR*DIA**2.)/AXMR
      RGTR=(WW*DIA**2.)/TRAN
      SD1=2.*(CL+RGAR*SA)
      SD2=CL-CD-(RGTR*DA)
   37 SD0=SD1/SD2
      SG1=1./SG
      SD=SD0*(2.-SD0)
   35 OPT=1
      GO TO 16
C     DETERMINE POINT OF IMPACT
   50 RATIO=-ZSAVE/DELZ
      XFINAL=RATIO*DELX+XSAVE
      XMFINL=XFINAL/3.281
      ZFINAL=RATIO*DELZ+ZSAVE
      ZMFINL=ZFINAL/3.281
      TFINAL=RATIO*(T-TSAVE)+TSAVE
      VXFNL=RATIO*DELVX+VXSAVE
      VZFNL=RATIO*DELVZ+VZSAVE
      VFINAL=SQRT(VXFNL*VXFNL+VZFNL*VZFNL)
      THEFNL=ATAN2(VZFNL,VXFNL)
      AXFNL=RATIO*(AX-AXSAVE)+AXSAVE
      AZFNL=RATIO*(AZ-AZSAVE)+AZSAVE
      AFINAL=SQRT(AXFNL*AXFNL+AZFNL*AZFNL)
      THACFL=ATAN2(AZFNL,AXFNL)
      DXFNL=RATIO*(DX-DXSAVE)+DXSAVE
      DZFNL=RATIO*(DZ-DZSAVE)+DZSAVE
      DFINAL=SQRT(DXFNL*DXFNL+DZFNL*DZFNL)
      THACFL=THACFL*180./3.14159
```

```
      THEFNL=THEFNL*180./3.14159
      WRITE(6,3) TFINAL,THEFNL,XMFINL,ZMFINL,VFINAL,AFINAL,
     1THACFL,DFINAL
    3 FORMAT(1X,15HPOINT OF IMPACT,/,3X,8F9.2)
C COMPARE SG TO SDO
      IF(JD.EQ.0)GO TO 379
      WRITE(6,381)PRATIO
  381 FORMAT(/,1X,42HRATIO OF EQUILIBRIUM ROLL/RESONANCE ROLL =,F10.4)
  379 IF(KOPT.NE.2) GO TO 471
      JA=1
  471 IF(JB.GT.0) GO TO 495
      IF(JA.EQ.1) GO TO 106
      WRITE(6,121)
  121 FORMAT(/,1X,23HSOLID FILLED PROJECTILE)
      GO TO 122
  106 WRITE(6,113)
  113 FORMAT(/,1X,24HLIQUID FILLED PROJECTILE)
  122 WRITE(6,101) SG
  101 FORMAT(/,1X,30HGYROSCOPIC STABILITY FACTOR = ,F10.4)
      WRITE(6,102) SDO
  102 FORMAT(/,1X,27HDYNAMIC STABILITY FACTOR = ,F13.4)
      IF(SG1.GE.SD) GO TO 210
      WRITE(6,205) SG1,SD
  205 FORMAT(/,1X,49HPROJECTILE IS STABLE SINCE : 1./SG < SDO(2.0-SDO),
     1F10.4,3H < ,F7.4)
      GO TO 495
  210 WRITE(6,220) SG1,SD
  220 FORMAT(/,1X,51HPROJECTILE IS UNSTABLE SINCE : 1./SG > SDO(2.0-SDO)
     1,F10.4,3H > ,F7.4)
  495 CONTINUE
  550 END
```

```
C THIS SUBROUTINE CALCULATES THE PROJECTILE SPIN
C DECAY ASSUMING VARIOUS LIQ SPINUP IN THE TUBE,B,
C W IS THE PERCENT DECAY AT TIME,TI, FOR A GIVEN B
      SUBROUTINE DECAY
      COMMON/BLK4/B,W,TI,TMAX
      IF(B.GT.0.0.AND.B.LT.1.0) GO TO 10
      WRITE(6,5)
    5 FORMAT(1X,21H ERROR PERCENT SPINUP)
      STOP
   10 W=B**TI
      TI=TI+.02
      IF(TI.LT.TMAX) GO TO 20
      TMAX=TI
      GO TO 70
   20 IF(W.GT.0.001) GO TO 70
      TMAX=TI
   70 RETURN
      END
```

```
C SUBROUTINE CALCULATES SPIN FOR A FIN MUNITION
C PE IS THE EQUILIBRIUM ROLL RATE.
C PR IS THE RESONANCE ROLL RATE
      SUBROUTINE FIN
      COMMON/BLK1/CSL,SFC,CLDP,OPT,P,T,
      COMMON/BLK2/DEN,V,S,DIA,DELT
      COMMON/BLK3/CM,SPIN,PRATIO,AXMS,TRAN
      REAL MU
      DOUBLE PRECISION SPI,E
      E=2.71828**T
      D1=-CSL/CLDP
      D2=(V*SFC)/DIA
      SPIN=D1*D2
      IF(T.EQ.5.) GO TO 50
      IF(P.EQ.SPIN) GO TO 50
      IF(P.LT.SPIN) GO TO 40
      SPI=SPIN+(P-SPIN)*(1./E)
      GO TO 45
   40 SPI=P+(1.-(1./E))*(SPIN-P)
   45 SPIN=SPI
   50 MU=.5*DEN*V**2.*S*DIA*CM
      IF(OPT.GT.0.) GO TO 30
      IF(CM.LE.0.0) GO TO 10
      WRITE(6,20)
   20 FORMAT(/,1X,45H SUBROUTINE REQUIRES NEGATIVE STATIC MOM COEF)
      STOP
   10 PR=(SQRT(-MU/(TRAN-AXMS)))/(2.*3.1416)
      PRATIO=SPIN/PR
   30 RETURN
      END
```

Table 1. Output for Spin-Stabilized Solid-Filled Projectile

TRAJECTORY PLOT

TIME (SEC)	TRAJ ANGLE (DEG)	HORIZ DIST (M)	VERT (M)	VEL (FT/SEC)	ACC (FT/SEC SQ)	ACC ANGLE DEG	DRAG (FTLB-SEC SQ)	CD	DEN (LB/FT CU)	SPIN (REV/SEC	YAW REAL (DEG)	YAW IMG (DEG)
.00	16.18	.00	6.10	1266.14	61.62	-133.72	4567.97	.36939	.07600	124.50	.000	.000
4.00	10.04	1389.18	334.03	1089.39	45.77	-126.17	2825.64	.32442	.07231	119.39	.220	.932
8.00	3.00	2648.27	480.31	1003.45	35.05	-110.56	1269.76	.17561	.07075	116.71	.271	1.082
12.00	-4.51	3843.55	465.66	963.33	32.86	-107.07	396.58	.14921	.07090	115.07	.310	1.207
16.00	-12.16	4991.30	297.78	943.95	31.56	-107.04	974.59	.14823	.07270	113.54	.314	1.206
POINT OF IMPACT												
19.82	-19.36	6045.17	.00	940.70	30.36	-107.75	1010.73					

SOLID FILLED PROJECTILE

GYROSCOPIC STABILITY FACTOR = 1.8597

DYNAMIC STABILITY FACTOR = .3809

PROJECTILE IS STABLE SINCE ; 1./SG < SD0(2.0-SD0) .5377 < .6167

Table 2. Output for Spin-Stabilized Liquid-Filled Projectile

TRAJECTORY PLOT

THEORETICAL LIQUID FILLED PROJECTILE SPIN

TIME (SEC)	TRAJ ANGLE (DEG)	HORIZ DIST (M)	VERT (M)	VEL (FT/SEC)	ACC (FT/SEC SQ)	ACC ANGLE DEG	DRAG (FTLB-SEC SQ)	CD	DEN (LB/FT CU)	SPIN (REV/SEC	YAW REAL (DEG)	YAW IMG (DEG)
.00	22.94	.00	6.10	1266.14	64.14	-129.55	4567.97	.36939	.07600	124.50	.000	.000
4.00	16.98	1333.26	495.05	1078.99	45.76	-120.77	2521.64	.30230	.07059	115.60	.213	.871
8.00	10.00	2549.95	789.65	987.40	35.37	-106.39	1041.63	.15611	.06756	113.32	.291	1.113
12.00	2.37	3712.91	917.32	937.12	33.61	-104.61	673.73	.14788	.06628	111.90	.356	1.347
16.00	-5.62	4834.31	886.30	908.11	32.37	-104.10	816.12	.14642	.06659	110.59	.390	1.453
20.00	-13.68	5917.08	702.16	898.14	31.26	-104.29	817.69	.14592	.06844	109.31	.380	1.400
24.00	-21.48	6962.09	370.33	904.39	30.12	-105.18	873.07	.14623	.07192	107.99	.334	1.216
POINT OF IMPACT												
27.22	-27.41	7775.33	.00	918.78	29.09	-106.47	956.97					

LIQUID FILLED PROJECTILE

GYROSCOPIC STABILITY FACTOR = 1.7077

DYNAMIC STABILITY FACTOR = 1.3250

PROJECTILE IS STABLE SINCE ; 1./SG < SD(2.0-SD) .5856 < .8944

Table 3. Output for Fin-Stabilized Solid-Filled Projectile

TIME (SEC)	TRAJ ANGLE (DEG)	HORIZ DIST (M)	VERT (M)	VEL (FT/SEC)	ACC (FT/ SEC SQ)	TRAJECTORY PLOT ACC ANGLE DEG	DRAG (FTLB- SEC SQ)	CD	DEN (LB/ FT CU)	SPIN (REV/ SEC	YAW REAL (DEG)	YAW IMG (DEG)
.00	51.00	.00	6.10	3850.00	143.04	-120.86	11671.66	.14501	.07600	385.00	.000	.000
20.00	42.86	12822.97	13995.62	2684.08	37.76	-98.49	761.76	.15700	.00943	378.09	-.368	.000
40.00	30.76	24605.85	22987.34	2224.89	32.97	-92.26	151.63	.17387	.00247	377.16	-2.152	.000
60.00	14.41	36201.17	27933.13	1956.39	32.33	-91.05	60.99	.18911	.00118	376.87	-5.689	.000
80.00	-4.78	47719.00	28934.91	1891.10	32.13	-90.89	50.23	.19356	.00102	376.69	-7.068	.000
100.00	-23.07	59172.41	26020.91	2035.35	31.85	-91.41	85.29	.18373	.00157	376.48	-3.904	.000
120.00	-37.65	70520.00	19234.89	2331.75	30.52	-94.21	283.32	.16901	.00432	376.03	-1.101	.000
140.00	-48.44	81535.56	8609.56	2625.37	22.83	-117.62	1537.34	.15878	.02043	374.22	-.160	.000
POINT OF IMPACT												
154.10	-54.60	88529.32	.00	2522.15	35.00	157.56	5530.97					

RATIO OF EQUILIBRIUM ROLL/RESONANCE ROLL = -.0154

IV. CONCLUSIONS.

The program analyzes projectile flight as shown by the sample outputs. These predictions for spin- and fin-stabilized projectiles will assist design personnel in evaluating a projectile flight. However, it should be noted that since the program does not take into account meteorological conditions, other than air density, and that it adapts simple particle trajectory theory, the output provides a good trajectory estimate for a projectile fired under normal conditions.

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